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METHOD OF DETERMINING RUBBING FRICTION
TORQUE IN A MOTOR VEHICLE POWERTRAIN

Technical Field

      This invention relates to rubbing friction torque in a motor vehicle
powertrain including an internal combustion engine, and more particularly to a
method of determining the rubbing friction torque.

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Background of the Invention

      The amount of torque an internal combustion engine must produce to
compensate the rubbing friction of the powertrain is customarily referred to as
the rubbing friction torque. In usual practice, the rubbing friction torque is

10   measured for various operating conditions during engine calibration, and stored
in a calibration table as a function of engine speed and powertrain temperature.
During subsequent engine operation, the engine controller accesses the rubbing
torque calibration table as part of its computation of engine output torque for
various control algorithms such as electronic throttle control and electronic

15   transmission control.

      Measuring the rubbing friction torque is ordinarily accomplished by
using an engine dynamometer to motor the engine under various combinations
of speed and coolant temperature. Obviously, this can be a costly and time-
consuming process, and can be performed for only a limited range of engine

20   temperatures. Other methods are also possible, such as calculating the rubbing
friction torque RFT during engine operation based on the relationship:

$$I\frac{d\omega}{dt} = IT - PFT - RFT$$

25   where I is the engine moment of inertia, $d\omega/dt$ is the engine acceleration, IT is
the indicated torque of the engine, and PFT is the retarding torque due to

pumping losses. But the moment of inertia I is difficult to estimate, and any estimation error is magnified by the engine acceleration which may be quite large. Although it is theoretically possible to obtain the test data at zero acceleration so that the term $I(d\omega/dt)$ is zero, such test conditions are difficult to

5 achieve as a practical matter. Accordingly, what is needed is a more comprehensive and cost-effective method for calibrating the rubbing friction torque of an engine.

Summary of the Invention

10 The present invention is directed to an improved method of determining the rubbing friction torque of a fully assembled motor vehicle powertrain, wherein the rubbing friction torque for any combination of engine speed and powertrain temperature is calculated in accordance with a base rubbing friction torque RFT_{base} determined at a base point powertrain temperature T_{base} and

15 calibration data characterizing fuel cutoff engine deceleration (DECEL) as a function of engine speed and powertrain temperature. The calibration data characterizing fuel cutoff engine deceleration is obtained by alternately enabling and cutting off engine fuel delivery to cycle the engine speed between specified set points, and measuring and recording the engine deceleration during intervals

20 of fuel cutoff. The rubbing friction torque RFT_{test} at a given test point is calculated from the base rubbing friction torque RFT_{base} according to:

$$RFT_{test} = \left(RFT_{base} + PFT_{base}\right) \times \frac{DECEL_{test}}{DECEL_{base}} - PFT_{test}$$

25 where $DECEL_{test}$ and $DECEL_{base}$ are the fuel cutoff engine decelerations at the test and base points, respectively, and PFT_{test} and PFT_{base} are the pumping friction torques at the test and base points, respectively.

Brief Description of the Drawings

30 Figure 1 is a diagram of a motor vehicle powertrain, a microprocessor-

based powertrain control module (PCM) and calibration instrumentation apparatus according to this invention.

Figure 2 is a graph depicting a control of engine speed carried out by the PCM of Figure 1 during characterization of fuel cutoff engine deceleration according to this invention.

Figure 3 is a graph depicting an extrapolation technique for determining a base rubbing friction torque according to this invention.

Figure 4 is a graph depicting fuel cutoff engine deceleration data measured by the instrumentation apparatus of Figure 1 for various powertrain temperatures and engine speeds.

Figure 5 is a process flow diagram depicting a determination of rubbing friction torque at any powertrain temperature and engine speed according to this invention.

Description of the Preferred Embodiment

Referring to the drawings, and particularly to Figure 1, the reference numeral 10 generally designates a motor vehicle powertrain, including an internal combustion engine (ENG) 12 and an automatic transmission (AT) 14. The engine output shaft 16 is coupled to the gear elements of transmission 14 through a fluid coupling or torque converter packaged with the transmission 14 and the transmission output shaft 18 is coupled to one or more drive wheels of the vehicle. The engine intake air is metered by throttle valve 20, a fuel control module (FCM) 22 injects fuel into the intake air to form an air/fuel mixture that is burned in the engine cylinders, and the combustion products are exhausted into exhaust manifold and header 24. The throttle valve 20 is coupled to a throttle actuator 26 that is controlled along with FCM 22 by a microprocessor-based powertrain control module (PCM) 28 to produce a desired engine output torque. Various input signals are provided to PCM 28 on lines 30, 32, 34 and 36. Line 30 carries an engine coolant temperature signal ECT produced by the temperature sensor 38, line 32 carries an engine speed signal ES produced by the speed sensor 40, line 34 carries a transmission oil temperature signal TOT

produced by the temperature sensor 42, and line 36 carries manifold absolute pressure signal (MAP) produced by the pressure sensor 44. The PCM 28 produces an output signal FUEL for FCM 22 on line 46 and a throttle control signal THR for actuator 26 on line 48.

5   In usual practice, the PCM 28 is programmed to operate in various modes including a calibration mode and a run mode. Typically, the calibration mode is used for the purpose of measuring and recording calibration data, and the method of this invention uses a calibration mode software routine for cycling the engine speed ES between specified setpoints such as 1000RPM and

10   6000RPM. In raising the engine speed ES to the high setpoint of 6000RPM, the PCM 28 controls FCM 22 and throttle actuator 26 to provide essentially wide-open-throttle acceleration of the engine 10; in subsequently lowering the engine speed ES to the low setpoint of 1000 RPM, the PCM 28 controls FCM 22 to cutoff the supply of fuel to engine 10. A short interval of such a control is

15   graphically illustrated in Figure 2, which depicts engine speed ES as a function of time.

Figure 1 additionally depicts a conventional calibration data logging instrument 50 for recording various parameters of interest during the above-described calibration mode engine control. Such parameters will typically

20   include not only the various inputs and outputs of PCM 28, but also certain other parameters that are not ordinarily measured in a production vehicle. For example, Figure 1 depicts a pressure sensor 52 responsive to the gas pressure in exhaust manifold 24 for producing an exhaust manifold pressure signal (EMP) on line 54.

25   The rubbing friction torque of a powertrain 10 such as depicted in Figure 1 will vary with both the engine speed ES and the operating temperature of the powertrain, which is characterized herein by the engine coolant temperature ECT (or alternately by the transmission oil temperature TOT). This relationship is reflected in the engine deceleration during the fuel cutoff intervals of the

30   calibration testing depicted in Figure 2, where the deceleration is the slope of the engine speed trace. In general, this invention recognizes that if the rubbing

friction torque of powertrain 10 is known at a base point powertrain temperature, the rubbing friction at any powertrain temperature can be simply calculated using the base point rubbing friction torque and fuel cutoff engine deceleration characterization data.

5   When the engine 12 is not producing torque due to fuel combustion, the product of the engine's moment of inertia I and deceleration dω/dt is equal to the sum of the pumping loss torque PFT and the rubbing friction torque RFT. That is:

$$I\frac{d\omega}{dt} = PFT + RFT \tag{1}$$

However, since the moment of inertia I is constant for any given engine, it can be concluded that:

$$\frac{RFT_1 + PFT_1}{RFT_2 + PFT_2} = \frac{DECEL_1}{DECEL_2} \tag{2}$$

where PFT_1 and PFT_2 are retarding torques due to pumping losses at two different powertrain temperatures signified by the subscripts 1 and 2, RFT_1 and RFT_1 are retarding torques due to rubbing friction torque at the two powertrain temperatures, and $DECEL_1$ and $DECEL_2$ are engine deceleration values due to the retarding torques. If the subscript "base" is used to represent data pertaining to a base point rubbing friction torque RFT_{base}, and the subscript "test" is used to represent data pertaining to a test condition other than the base point, equation (1) may be rewritten as:

$$RFT_{test} = \left(RFT_{base} + PFT_{base}\right) \times \frac{DECEL_{test}}{DECEL_{base}} - PFT_{test}$$
$$\Rightarrow RFT_{test} = \left[RFT_{base} \times \left(\frac{DECEL_{test}}{DECEL_{base}}\right)\right] + \left[PFT_{base} \times \left(\frac{DECEL_{test}}{DECEL_{base}}\right) - PFT_{test}\right] \tag{3}$$

In many cases, the second term of the above equation can be neglected if the testing is performed with engine 12 at wide-open throttle, which minimizes pumping losses. Additionally, test data shows that pumping friction torque is proportional to deceleration, so that $(PFT_{base} * DECEL_{test})/DECEL_{base}$ is very

5 nearly equal to PFT_{test}.

Thus, the calibration process according to this invention involves the steps of (1) determining a base point rubbing friction torque RFT_{base} at a base powertrain temperature T_{base}, (2) characterizing the fuel cutoff engine deceleration in terms of powertrain temperature and engine speed, and (3)

10 computing and tabulating the rubbing friction torque for various combinations of powertrain temperature and engine speed by applying the base and deceleration characterization data to equation (3). This process is outlined by the process flow diagram of Figure 5, as explained below.

The base rubbing friction torque can be obtained by various techniques,

15 including those discussed in the background portion hereof. An alternative technique is to estimate the rubbing friction torque during engine operation at a given powertrain temperature, and then extrapolate the data to a zero fuel-flow condition (i.e., a condition where the indicated torque IT is zero). This is illustrated by the graph of Figure 3, which depicts the rubbing friction torque

20 RFT as a function of fuel flow (in grams/sec) at a constant engine speed of 4400RPM. The rubbing friction torque RFT data is obtained by measuring the brake torque BT of the engine 12 or powertrain 10 with a dynamometer, determining the indicated torque IT and pumping loss torque PFT from measured data and combustion analysis, and solving the following torque

25 balance equation for RFT:

$$BT = IT - PFT - RFT \qquad (4)$$

The solid portion of the trace in Figure 3 represents the measured test data,

30 whereas the broken portion of the trace designates an extrapolation of the measured test data for purpose of estimating RFT at zero fuel flow.

Figure 4 graphically depicts representative engine deceleration data obtained during the fuel cutoff intervals of the engine calibration testing depicted in Figure 2. The various traces ECTa-ECTg represent deceleration data as a function of engine speed ES for various engine coolant temperatures,

5   with trace ECTa representing a relatively low engine coolant temperature such as 24°C, and trace ECTg representing a relatively high engine coolant temperature such as 88°C. As mentioned above, transmission oil temperature TOT or another powertrain temperature could be used in place of the engine coolant temperature ECT, if desired. As indicated by the traces, the engine

10   deceleration decreases with increasing powertrain temperature, and generally decreases with decreasing engine speed ES. In practice, the characterization data represented by the traces ECTa-ECTg can be tabulated in calibration instrument 50 so that the engine deceleration for any given combination of ES and ECT bounded by the traces ECTa-ECTg may be determined by

15   interpolation.

As indicated above, once a base rubbing friction torque RFT_{base} is determined at a base powertrain temperature T_{base}, and the data characterizing fuel cutoff deceleration (as represented by the traces of Figure 4) is obtained, the rubbing friction torque RFT_{test} at any other combination of engine speed and

20   powertrain temperature (ES_{test}, T_{test}) may be determined using equation (3). Referring to the process flow diagram of Figure 5, the blocks 60 and 62 pertain to obtaining the base rubbing friction data. As indicated at block 60, RFT_{base} may be obtained by the extrapolation technique described above in respect to Figure 3, or by the conventional engine dynamometer technique. The term

25   ($RFT_{base} + PT_{base}$) appearing at block 62 is obtained at several different engine speed values, all at base temperature T_{base}. Block 64 represents the step of characterizing the engine deceleration by obtaining data in the fuel cutoff intervals of the engine depicted in Figure 2; the resulting data is represented by the traces ECTa-ECTg in Figure 4, and is tabulated in calibration instrument 50.

30   The blocks 66, 68 and 70 designate the rubbing friction calculation performed by calibration instrument 50 once the steps designated by blocks 60-64 have

been completed. An engine speed and powertrain temperature operating point (ES_{test}, T_{test}) is chosen at block 66, and the corresponding rubbing friction torque is determined at blocks 68 and 70. Block 68 designates the step of obtaining $DECEL_{base}$ and $DECEL_{test}$ from the engine deceleration characterization data.

5 The term $DECEL_{base}$ is the fuel cutoff engine deceleration corresponding to the base temperature T_{base} and the selected engine speed ES_{test}; the term $DECEL_{test}$ is the fuel cutoff engine deceleration corresponding to the selected temperature T_{test} and the selected engine speed ES_{test}. Finally, the block 70 designates the step of calculating a rubbing friction torque RFT_{test} based on (RFT_{base} +

10 PFT_{base}), $DECEL_{base}$, $DECEL_{test}$ and PFT_{test} using equation (3). The process flow line 72 indicates that the steps 66, 68 and 70 are repeated for various combinations of ES_{test} and T_{test}, with the calculated rubbing friction torque values being stored in a look-up table within PCM 28 as a function of ES and powertrain temperature.

15 In summary, this invention provides a more comprehensive and cost-effective method of calibrating the rubbing friction torque of a motor vehicle powertrain, compared to known methods. Extended engine dynamometer testing is no longer required, and the data can be obtained in a fully assembled powertrain, using the PCM 28 to set up the conditions for characterizing fuel

20 cutoff engine deceleration. Once the base rubbing friction data and the fuel cutoff deceleration data are obtained, the calibration data may be obtained in an automated manner by simply calculating the rubbing friction torque for various combinations of ES and ECT to build a two-dimensional calibration table for PCM 28. While the present invention has been described in reference to the

25 illustrated embodiment, it is expected that various modifications in addition to those mentioned above will occur to those skilled in the art. Thus, it will be understood that methods incorporating these and other modifications may fall within the scope of this invention, which is defined by the appended claims.